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Regulation of the SCOLE Configuration

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REGULATION OF

THE SCOLE CONFIGURATION

INVESTIGATORS

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PERFORMANCE REQUIREMENTS

(I) MAINTAIN RMS OF THE STEADY STATE LINE-OF-SIGHT (LOS) ERROR WITHIN A SPECIFIED BOUND.

(II) MAINTAIN STEADY STATE ACTUATOR VARIANCES AS CLOSE AS POSSIBLE TO SPECIFIED BOUNDS.

ORIGINAL SCOLE CONFIGURATION

- LOCATION OF 2 PROOF MASS ACTUATORS NOT SPECIFIED.

- 42 SENSORS PROVIDED.

OBJECTIVES

(I) DETERMINE LOCATIONS FOR PROOF MASS ACTUATORS.

(II) DETERMINE A REDUCED SET OF SENSORS.

(III) DESIGN A CONTROL LAW TO MEET PERFORMANCE REQUIREMENTS FOR LOS ERROR AND ACTUATORS.

- SOLUTIONS TO THE 3 PROBLEMS ARE INTERDEPENDENT.
- CHOICE OF ACTUATORS AND SENSORS INFLUENCES CONTROL LAW.
- CHOICE OF CONTROL LAW INFLUENCES SENSOR AND ACTUATOR SELECTION.

LINEARIZED DYNAMICAL MODEL

VECTOR SECOND ORDER MODAL FORM

$$\ddot{\eta} + D\dot{\eta} + \Omega^2\eta = \bar{B}(u+w)$$

output vector y

$$y_1 = LOS_x \ , \quad y_2 = LOS_y \ , \quad y_3 = LOS_z$$

$$E(LOS\ error)^2 = (Ey_1^2 + Ey_2^2 + Ey_3^2)^{1/2}$$

$$y = C_p \eta$$

measurement vector z

$$z_{p,r} = \text{position \& rate measurement vector}$$
$$= P_p\eta + P_v\dot{\eta} + v_{p,r}$$
$$z_a = \text{acceleration measurement vector}$$
$$= Q\ddot{\eta} + v_a$$
$$= Q(-\Omega_\eta^2 - D\dot{\eta} + \overline{B}u + \overline{B}w) + v_a$$
$$z = \begin{bmatrix} z_{p,r} \\ z_a - Q\overline{B}u \end{bmatrix} = M_p\eta + M_v\dot{\eta} + v$$

where

$$M_p = \begin{bmatrix} P_p & 0 \\ 0 & -Q\Omega^2 \end{bmatrix}$$
$$M_v = \begin{bmatrix} P_v & 0 \\ 0 & -QD \end{bmatrix}$$
$$v = \begin{bmatrix} v_{p,r} \\ v_a + Q\overline{B}w \end{bmatrix}$$

=> ASSOCIATED SENSOR NOISE (v) & ACTUATOR NOISE (w) ARE CORRELATED

- MODEL OBTAINED USING CUBIC BEAM ELEMENT SHAPE FUNCTIONS FOR BEAM BENDING AND LINEAR SHAPE FUNCTION FOR BEAM TWIST.

- 32 MODES IN ORIGINAL MODEL.

- MODAL COST ANALYSIS USED TO REDUCE TO 23 MODE DESIGN AND EVALUATION MODEL.

MODAL COST ANALYSIS

modal cost rank	mode no.	modal cost	freq. (hz)	mode type
1	1	infinite	0	rigid body
2	2	infinite	0	rigid body
3	3	infinite	0	rigid body
4	5	.911e+07	.299e+00	bending (roll)
5	7	.363e+07	.118e+01	bending
6	4	.336e+07	.276e+00	bending (pitch)
7	6	.138e+07	.811e+00	bending
8	8	.955e+06	.205e+01	bending
9	10	.673e+04	.551e+01	bending
10	9	.556e+04	.478e+01	bending
11	11	.246e+02	.123e+02	bending
12	14	.365e+01	.243e+02	bending
13	17	.245e+01	.395e+02	twist
14	12	.305e+00	.129e+02	bending
15	16	.116e+00	.390e+02	bending
16	15	.349e-01	.256e+02	bending
17	26	.995e-02	.109e+03	bending
18	25	.377e-02	.103e+03	bending
19	13	.376e-02	.237e+02	bending
20	29	.174e-02	.140e+03	bending
21	35	.836e-03	.215e+03	bending
22	20	.597e-03	.586e+02	bending
23	28	.370e-03	.139e+03	bending
24	23	.125e-03	.817e+02	bending
25	19	.310e-04	.581e+02	bending
26	34	.275e-04	.215e+03	bending
27	32	.617e-05	.175e+03	bending
28	31	.294e-05	.175e+03	bending
29	27	.131e-05	.135e+03	twist
30	24	.140e-07	.106e+03	twist
31	30	.134e-07	.167e+03	twist
32	33	.413e-08	.200e+03	twist
33	22	.298e-10	.811e+02	bending
34	18	.340e-11	.515e+02	twist
35	21	.226e-13	.702e+02	twist

- FIRST 5 FLEXIBLE MODES DOMINATE MODAL COST

- BEAM BENDING DOMINATES MODAL COST

CONTROL LAW DESIGN VIA
THE OUTPUT VARIANCE ASSIGNMENT ALGORITHM

- ITERATIVE ALGORITHM DEVELOPED BY SKELTON AND DELORENZO

- OBJECTIVE IS TO CHOOSE DIAGONAL Q AND R IN THE LQG COST FUNCTIONAL

$$\nu = E_\infty(y^T Q y + u^T R u)$$

S.T. THE LQG CONTROL LAW SATISFIES

$$E_\infty y_i^2 = \sigma_i^2 \quad (\text{or} < \sigma_i^2) \quad \forall \quad i = 1 \to n_y$$

WHILE MINIMIZING

$$\sum_{i=1}^{n_u} \frac{E_\infty u_i^2}{\mu_i^2} .$$

bounds on input variances

SENSOR AND ACTUATOR SELECTION

VIA INPUT/OUTPUT COST ANALYSIS

- SUBOPTIMAL APPROACH.

- BASED ON DECOMPOSING COST FUNCTION

$$\nu = E_\infty(y^T Q y + u^T R u)$$

as

$$\nu = \sum_{i=1}^{n_y} \nu_i^y + \sum_{i=1}^{n_u} \nu_i^u$$

$$\nu = \sum_{i=1}^{n_u} \nu_i^w + \sum_{i=1}^{n_z} \nu_i^v .$$

- DEFINES ACTUATOR EFFECTIVENESS,

$$\nu_i^{act} = \nu_i^u - \nu_i^w$$

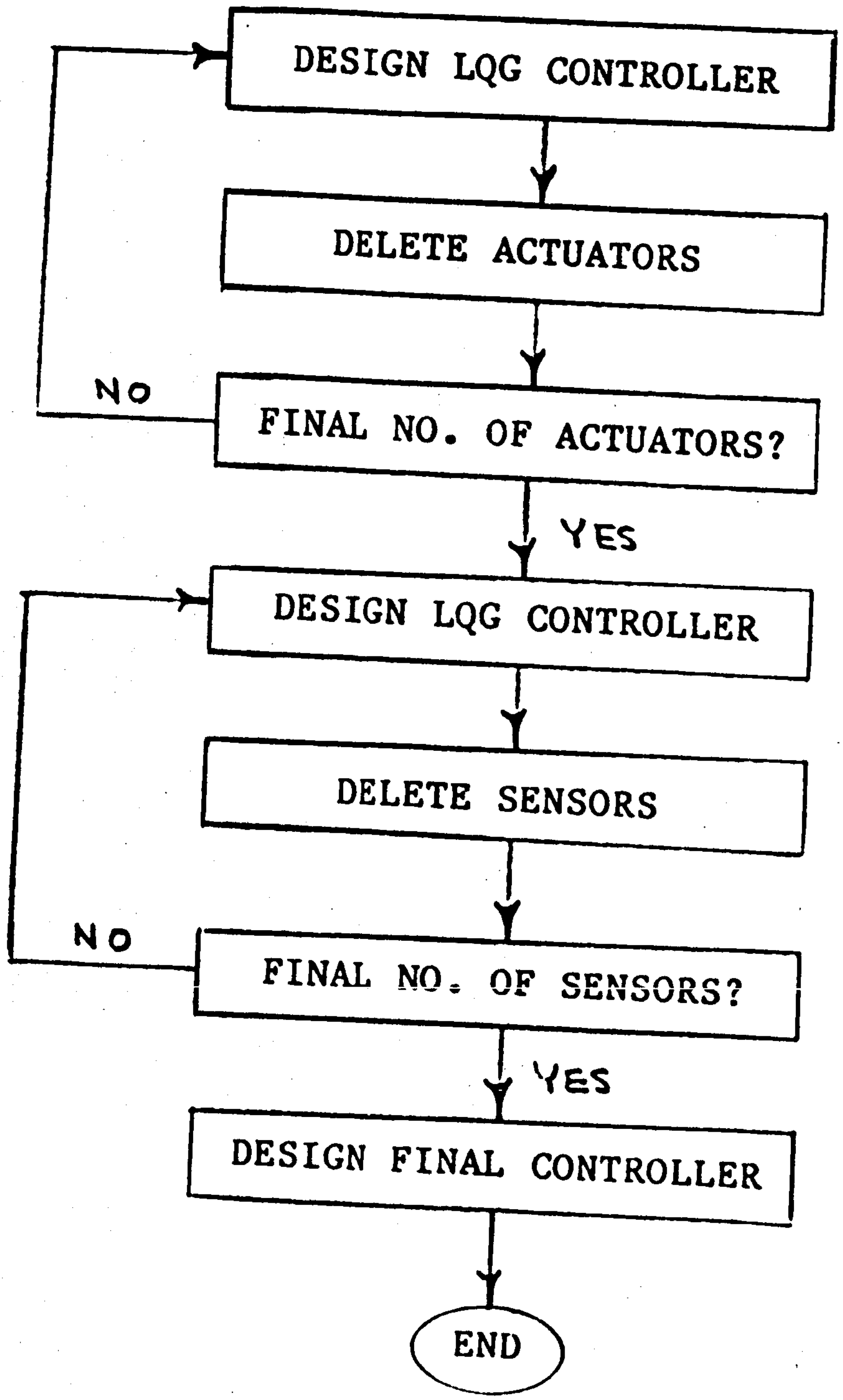
AND SENSOR EFFECTIVENESS

$$\nu_i^{sen} = \nu_i^v .$$

- DELETES ACTUATOR(S) OR SENSOR(S) WITH LOWEST EFFECTIVENESS VALUES.

SOLUTION PROCEDURE

- BEGIN WITH LARGE SET OF PROOF MASS ACTUATORS AT FIXED LOCATIONS



SOME RESULTS

ORIGINAL SCOLE PROPOSAL

rms(los error) < .02 deg

OUR FINDINGS

if noise through shuttle cmgs only:

rms(los error) > .045 deg

if equivalent noise through all actuators:

rms(los error) > .075 deg

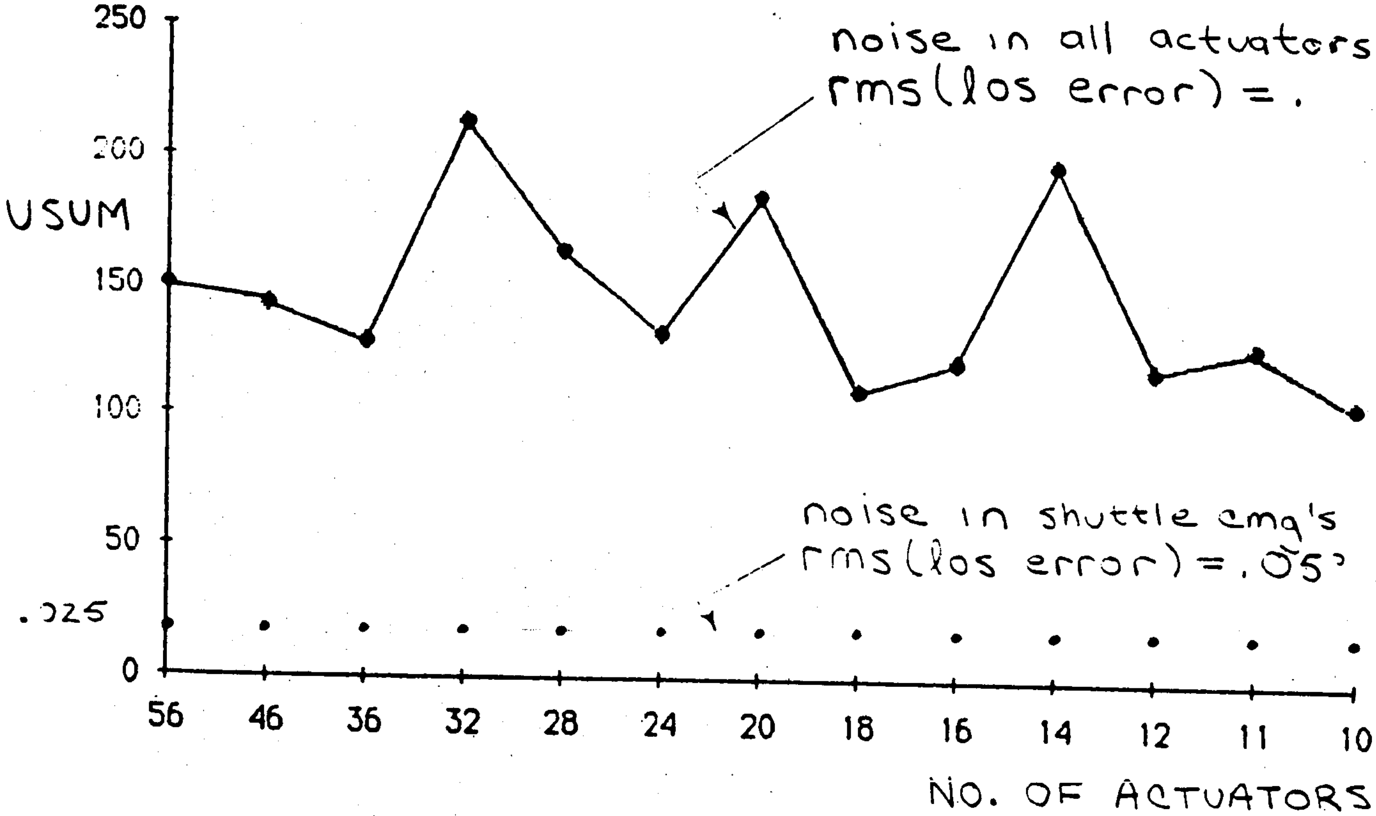
CONCLUSIONS

- ORIGINAL SPECS ON LOS ERROR ARE NOT ACHIEVABLE.
- MUST MODIFY LOS SPECS.

ACTUATOR SELECTION

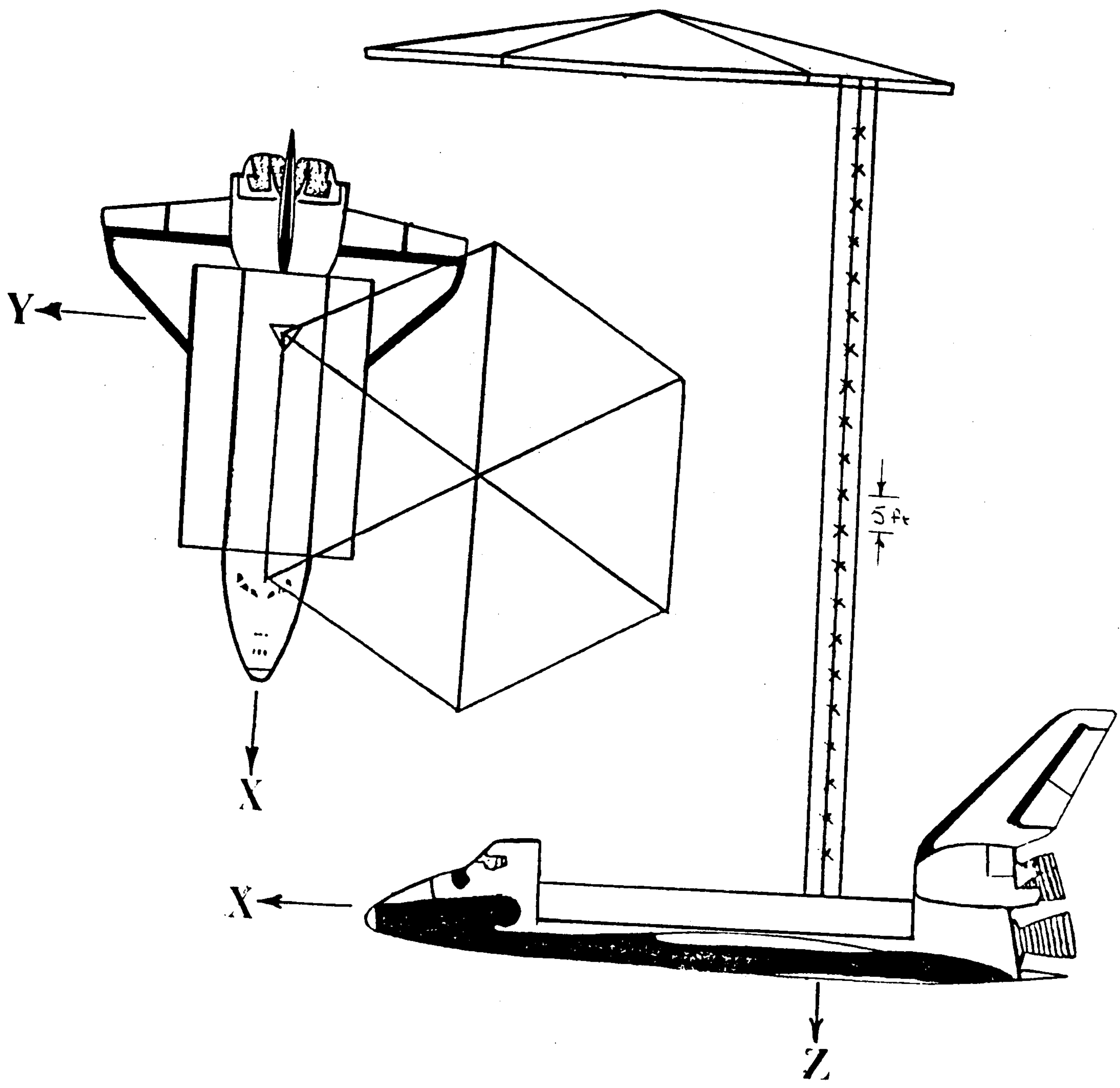
DEFINE

$$USUM = \sum_{i=1}^{n_u} \frac{Eu_i^2}{\mu_i^2} = \text{dimensionless measure of total control effort}$$



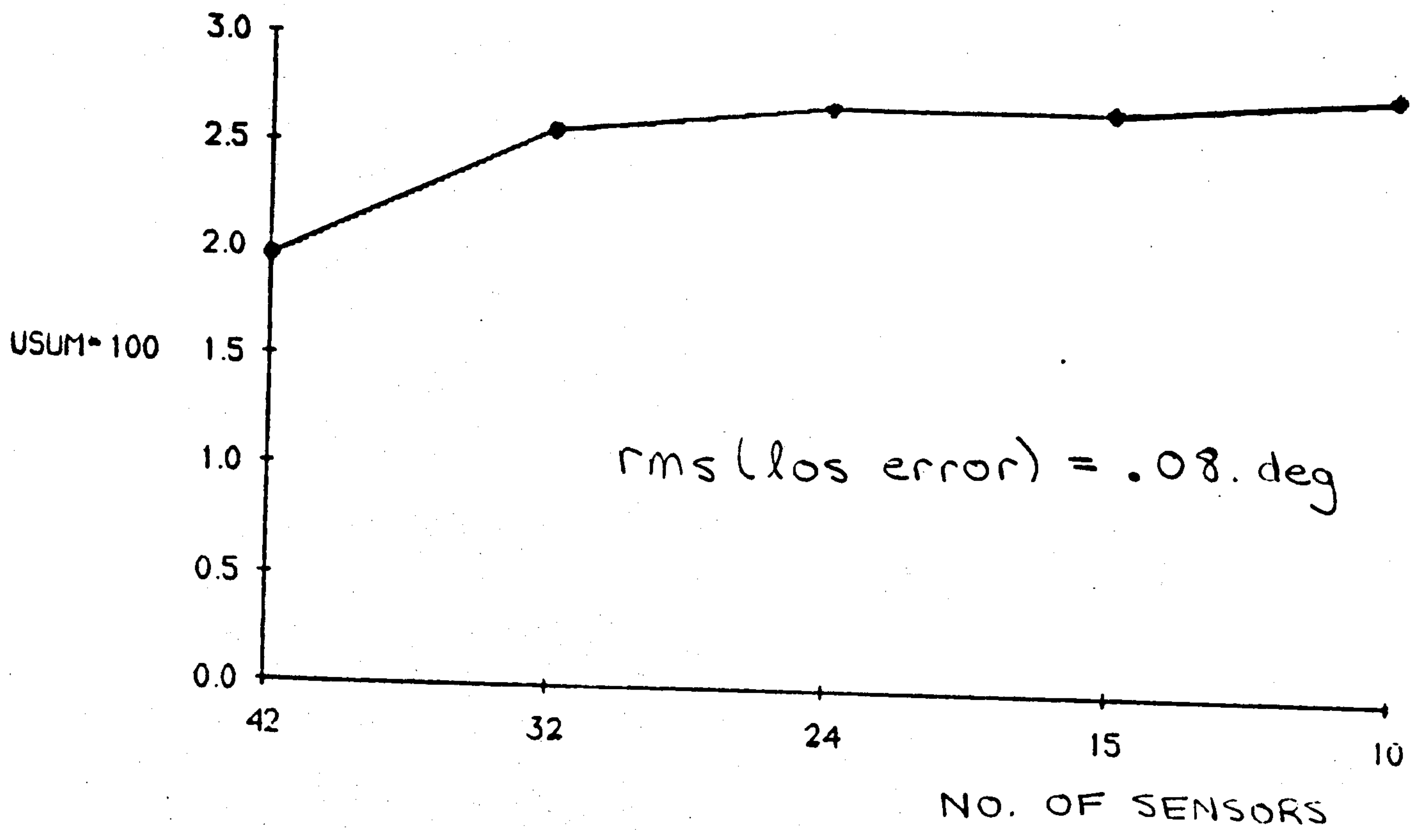
FINDINGS

- BY USING REDUCED SET OF ACTUATORS THERE IS A 50% SAVINGS IN CONTROL EFFORT (AS MEASURED BY USUM).



- PROOF MASS ACTUATORS NEAR TOP OF THE BEAM ARE MORE EFFECTIVE

SENSOR SELECTION



- GOOD PERFORMANCE MAY BE ACHIEVED WITH A MUCH SMALLER SET OF SENSORS.

CONCLUSIONS

(I) RMS(LOS ERROR) $\leq$ .02 DEG IS NOT ACHIEVABLE.

RMS(LOS ERROR) $\leq$ .05 DEG IS ACHIEVABLE IF NOISE IS ONLY THROUGH SHUTTLE CMG'S.

RMS(LOS ERROR) $\leq$ .08 DEG IS ACHIEVABLE IF (EQUIVALENT) NOISE IS THROUGH ALL ACTUATORS.

(II) PROOF MASS ACTUATORS SHOULD BE PLACED NEAR TOP OF MAST.

(III) GOOD PERFORMANCE MAY BE ACHIEVED WITH A (SIGNIFICANTLY) REDUCED SET OF SENSORS.